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CHOOSING A MODEL OF SENTENCE PICTURE COMPARISONS: A REPLY TO CATLIN AND JONES

Edward J. Shoben

University of Illinois at Urbana-Champaign

February 1978

Center for the Study of Reading

UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN
51 Gerty Drive
Champaign, Illinois 61820

The National Institute of Education
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BOLT BERANEK AND NEWMAN INC.
50 Moulton Street
Cambridge, Massachusetts 02138

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Abstract

In a recent note, Catlin and Jones (1976) argued that the sentence picture comparison model of Carpenter and Just could not account for the results obtained in studies where the picture preceded the sentence. In the present note, it is argued that the model can handle the results without adding additional parameters and that the Carpenter and Just proposal remains a viable theory of sentence picture comparisons.

Choosing a Model of Sentence Picture Comparisons: A Reply to Catlin and Jones[1]

Perhaps the most highly developed models of sentence comprehension are the sentence picture comparison models. Both the model of Clark and Chase (1972) and the constituent comparison model of Carpenter and Just (1975) focus primarily on the question of how people compare information in sentences with that presented in pictures. More generally, however, these models seek to identify how people decide if the presented information is consistent with their prior knowledge. Thus while the experimental investigations of these models have concentrated heavily on some rather simple sentence picture comparisons, both models are models of sentence comprehension and not just models of the sentence picture task. Indeed, both theoretical papers devote considerable attention to the generalizability of their respective models. As the problem of sentence comprehension is clearly basic to many areas of psychology, evidence favoring one of these models over the other is particularly important.

In a recent note, Catlin and Jones (1976) contended that the constituent comparison model of sentence verification should not be regarded as a viable model of comprehension. Their major argument against the Carpenter and Just (1975) model is that while one aspect of the fitted model (negation time)[2] remains relatively constant across tasks, a second aspect (falsification time) does not. In examining the available data on sentence picture comparisons, Catlin and Jones correctly noted a systematic difference between studies in which the sentence preceded the picture and those in which the picture preceded the sentence. More specifically the ratio of negation time to falsification time (NT/FT) is 4:1 in the sentence first condition and 2:1 in the picture first condition. Catlin and Jones further noted that this change in ratio results from a change in falsification time. This finding contrasts with the suggestion of Carpenter and Just who attribute the change in ratio to a change in negation time.

While this finding does pose a problem for the Carpenter and Just model, it will be argued in the present note that the constituent comparison model can predict the difference in falsification time by adding a single assumption and without adding a single parameter, thereby attenuating the force of the Catlin and Jones critique. Moreover, Catlin and Jones appear to have overlooked the best single piece of evidence to support their contention, which is the finding that falsification time for picture first experiments using "below" is in fact negative, resulting in a negative NT/FT ratio (Clark & Chase, 1972). Following Catlin and Jones, falsification time and negation time are used here as empirical, not theoretical, constructs. In neither the Clark and Chase model nor the Carpenter and Just model do any of the parameters have the undesirable and implausible attribute of being less than zero milliseconds.

Tables 1 and 2 present the results from Experiment 2 from Clark and Chase (1972). In one part of this study, subjects were required to read a sentence, such as "The star is above the plus," and then examine a picture, such as $\left(\begin{smallmatrix}*\\+\end{smallmatrix}\right)$. Subjects then had to decide if the sentence was an accurate description of the picture. In the other part of the experiment, subjects also had to decide if the sentence matched the picture, but the picture preceded the sentence. For the sentence first condition, the results for both the "above" and the "below" condition exhibit an NT/FT ratio that is roughly 4:1. In contrast, the picture first results exhibit a marked dependence on type of preposition.

Insert Tables 1 and 2 about here

In the "above" condition, the NT/FT ratio is 2:1 (negation time = 528 msec; falsification time = 304 msec) but in the "below" condition, the ratio is <u>negative</u> (negation time = 481 msec, falsification time = -121 msec), where the change in ratio is mainly due to the change in falsification time. At first glance, these results seem directly at odds with the constituent comparison model, as there is no provision in the model for a negative falsification time.

More generally, Carpenter and Just do not deal with the picture first case in sufficient detail. In the experiment just described, the distinction between sentence first and picture first is important, as Clark and Chase noted. When the sentence precedes the picture, the sentence can guide the coding of the picture so that the grammatical subjects (as in Clark and Chase) or prepositions match. When the picture is first, however, the coding of the picture is necessarily independent of the sentence. In this latter case, the Carpenter and Just model is incomplete in that they do not describe how the picture is encoded.

Moreover, assuming the picture is coded as (Plus above star), how does the subject determine that this representation of the picture in fact matches (Star below plus), the representation of the sentence?

Thus, it seems that Catlin and Jones are correct when they assert that the Carpenter and Just treatment of picture first results is incomplete. But this inadequacy does not necessarily mean that the theory is empirically wrong. In fact, quite reasonable assumptions, similar to those made by Clark and Chase, will enable the Carpenter and Just model to account for the problematic results.

These additional assumptions deal with the need for recoding in the picture first condition, and produce no alteration in the predictions in the sentence first condition.[3] In fact, these assumptions are similar in spirit to the ones which Carpenter and Just themselves propose to handle cases where subjects convert negative sentences into affirmative ones. The hypothesized representations, comparison processes, and predictions of NT/FT for the sentence first condition are given in Table 3.

The assumptions for the sentence first condition are identical to the ones originally proposed by Carpenter and Just (1975). The sentences are represented as shown in Table 3 and the processing proceeds outward from the most embedded component. The major assumption is that processing continues until a mismatch is detected. At this point, the mismatch is tagged and processing begins again at the most embedded constituent. The number of restarts is an important determiner of difficulty; true negatives are the most difficult condition and they require the most restarts. Similarly, the importance of the place at which the mismatch is detected is evident in a comparison of the false affirmatives with the false negatives.

Insert Table 3 about here

The predictions generated by these assumptions may be compared to the results in Tables 1 and 2 and to the studies surveyed by Catlin and Jones (p. 498). While the NT/FT ratios observed in Tables 1 and 2 exceed 4:1 considerably, it should be noted that these results are among the highest for studies of this type. Furthermore, small differences in falsification time have a profound influence on the NT/FT ratio. For example, an increase of 45 msec in FT for the sentence first results of Tables 1 and 2 would reduce the two NT/FT ratios to 3.77:1 and 4.29:1.

In the sentence first condition, we allowed the coding of the sentence to guide the coding of the picture. When the picture occurs first, we must make different assumptions. Following Clark and Chase, we will assume that the picture is always coded in terms of the unmarked or preferred preposition (i.e., above) and that in order to compare inner strings, the grammatical subjects must match. For example, if the picture $\binom{*}{+}$ is followed by the sentence "The plus is above the star," the picture will be encoded as (Star above plus), and the sentence code T(Plus above star) must be recoded to T(Star below plus). Finally, it is assumed that the detection of the need to recode and the recoding itself take time. Consistent with the notions of markedness (Clark & Chase, 1972), it is assumed further that it requires two recoding steps to convert the linguistically more complex below to above, but only one step to convert the simpler above to below. To preserve the spirit of the Carpenter and Just model, we will also add the extremely restrictive assumption that each conversion operation requires the same amount of time as one comparison operation.

As these two assumptions are critical to the predictions derived below, one might reasonably ask if they have any support. With respect to the first assumption, Carpenter and Just note in their original paper (p. 65) that equating the time required to convert a constituent with the time required to compare constituents produced a very good fit of the model to the data. Thus the recoding assumption is not really a new assumption; it is merely an application of an old assumption to a new context. The truly new assumption is that it is more difficult to recode below than above. One possible source of evidence on this question is free association norms. If it were the case that below was a more common associate of above than above was of below, then we would have some evidence for our assumption. Unfortunately, it was not possible to find norms for both these terms. Consequently, two classes were asked to write down their first associate of one of these prepositions. In the class asked to associate to above, 86.5 percent of the students gave below as their first associate. In contrast, only 55.3 percent of the students in the class asked for an associate of below gave above as their first response. This difference was highly reliable ($z = 2.97$, $p < .003$). While these results provide evidence that below to above is the harder recoding, there is no evidence that this operation is exactly twice as difficult as recoding above to below. Moreover, it may be that other such pairs will show a different pattern. Nonetheless, while the ratio of difficulty has no empirical support, there is some evidence that the assumption of differential difficulty is reasonable.

These assumptions, very similar to ones made by Clark and Chase, enable us to derive predictions for the processing of picture first comparisons, which are shown in Table 4. It is important to notice

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Insert Table 4 about here

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three attributes of Table 4. First, negatives are represented just as they were in sentence first comparisons (cf. Table 3). There is no need, with the present assumptions, to assume that which representation comes first affects the treatment of the negative. Secondly, despite the fact that negatives are always represented in the same way, the derived NT/FT ratio for the "aboves" is only 2:1, as it should be, and, consistent with the data summarized by Catlin and Jones, the decrement in the ratio derives from an increase in falsification time. Lastly, this expanded model predicts the negative falsification time for the "below" condition, which is also evident in Table 2.

In the picture first condition, the times predicted by the revised model will depend largely on whether recoding is required or not. When the sentence contains "above," the derivation of the predictions is shown in the top half of Table 4. True affirmatives (TAs) will be fast, since the grammatical subject of both the sentence code and the picture code is the same, and, as a consequence, the two representations can be compared immediately. No mismatches are detected and thus only *k* comparisons are required. In the false affirmatives (FAs), recoding is necessary as the picture is represented as (Plus above star) and the sentence as T(Star above plus). Following our assumption that grammatical subjects must match before strings can be compared, (Star above plus) must be recoded as (Plus below star). Since we also assumed that the time required to detect the need for and to perform the recoding was equal to one comparison (in the "above" case), FAs thus require *k + 2* comparisons. The predictions for negatives are derived in the same way. Notice that in all cases the sentences are represented just as they were in the sentence first condition. For false negatives (FNs) no recoding is required since the subjects of the inner strings match. The comparison process therefore proceeds as in the sentence first condition and *k + 4* comparisons are required. In the true negative (TN) case, the picture is coded as (Plus above star) and the sentence as F(T[Star above plus]). Since the inner strings do not have the same subject, recoding must occur. As noted above, this recoding operation from above to below is assumed to require only one comparison. After the recoding, the comparison proceeds as in the sentence first condition and thus the total number of comparisons required is *k + 5 + 1* (for the recoding) or *k + 6* comparisons.

The derivation for negation time and falsification time is shown at the bottom of Table 4. Negation time remains the same as in the sentence first condition, but falsification time doubles. This is precisely the result observed by Catlin and Jones.

For the "below" case, the predictions are the reverse of the "above" case in that recoding must occur in TAs and FNs, but not in FAs and TNs. For the TAs, the subjects of the inner strings do not match, and thus, using the example given in Table 4, (Star below plus) must be recoded as (Plus above star) before the comparison process can begin. Following our earlier assumption, the time required to detect the need to recode and to perform the recoding operation in this "below" condition is equal to two comparisons. Therefore, the total time needed to solve a "below" TA is k + 2 comparisons. For FAs, the number of comparisons required is identical to the number required in the sentence first condition, k + 1. Note that since no recoding is required, we predict the counterintuitive and seldom noted fact that FAs are faster than TAs in this case.

A similar pattern holds for the below negatives. FNs must be recoded, requiring two additional comparisons to convert (F[T(Plus below star)]) to (F[T(Star above plus)]), resulting in a total of k + 6 comparisons. For TNs, no recoding is necessary since the inner string subjects match and hence k + 5 comparisons are required as in the sentence first case.

This analysis enables us to predict the "below" results of Table 2. In addition, the revised model predicts an NT/FT ratio of 4:-1 which is almost exactly the result found by Clark and Chase. The present revision of the constituent comparison model is thus able to handle the negative NT/FT ratio in the picture first below condition and also the major objection raised by Catlin and Jones: namely, that falsification time, but not negation time, changes with which stimulus is presented first. Moreover, the added assumptions do not require additional parameters to be added to the model.

It is also reasonable to ask how well the revised model fits available data. More specifically, do the additional assumptions enable the revised constituent comparison model to achieve a quantitative fit of the Clark and Chase picture first (1972) data presented in Tables 1 and 2? We can attempt to fit these data in two ways: following Carpenter and Just, we can fit the model separately for "above" and "below," or we can perform a more stringent test of the model by trying to fit the "above" and "below" data together. The fit of the model in this latter, more exacting, test is shown in Table 5. This overall fit accounts for 97.4% of the variance among the eight means. Even with the relatively large number of data points (Carpenter and Just typically fit four means, with a maximum of six), the variance accounted for by the revised model is in the range achieved by the two other major models. In this particular case, the fitted regression line has an intercept of 1860 msec with a slope of 130 msec per comparison. The overall RMSD is 46 msec.

Insert Table 5 about here

The fit of the model to the data is of course improved if the "above" results and the "below" results are fitted separately. Predicted and observed values are given in Table 6. For the "above" results, the revised model accounts for 99.1% of the variance, with an RMSD of 28 msec. The slope of the best fitting equation is 136 msec per comparison, with an intercept of 1812 msec. For the "below" results, the fit is almost as good; the model accounts for 98.6% of the variance, with an RMSD of 29 msec. The slope of 120 msec per comparison is comparable to the slope obtained with the "above" results; however, the intercept for the "below" equation is 1928 msec, substantially higher than the 1812 obtained for the "above" straight line.

Insert Table 6 about here

In short, the revised model fits the problematic picture first data extremely well. While Catlin and Jones are undoubtedly right that arguments about variance accounted for may not enable us to confirm any particular model, the excellent fits obtained with the present revision certainly enable the model to pass the first test of sufficiency.

One might argue that the present assumptions detract from the simplicity of the Carpenter and Just model and are *ad hoc*. While these assumptions were proposed to account for particular results, two points can be made. First of all, the assumptions are theoretically consistent with Carpenter and Just's approach to recoding in general, in which they propose that recoding of a constituent requires one comparison operation. Secondly, the assumptions are a more restrictive version of the ones adopted by Clark and Chase, who treat subject recoding time as a free parameter. Moreover, even with these assumptions, it is still the case that the revised model fits all data with only one parameter (plus an intercept).

This analysis does not demonstrate that the Carpenter and Just model is correct, or even that it is to be preferred over the Clark and Chase proposal; this paper asserts only that the Carpenter and Just proposal should not be rejected for the reasons put forward by Catlin and Jones. One rather straightforward test of the Carpenter and Just proposal is a statistical one. One could test the predicted NT/FT ratios of the original model and the proposed revision either by the calculation of maximum likelihood ratios or by a simple t-test. One could perform the latter by computing NT/FT ratios for each subject and then testing them against the theoretical value. There are undoubtedly other definitive tests of the model, but it seems ill-advised to reject it on the basis of results which the model can assimilate easily with quite reasonable additional assumptions.

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Footnotes

[1]Requests for reprints should be addressed to the author whose address is Department of Psychology, University of Illinois, Champaign, IL 61820.

[2]As Clark and Chase first noted, negation time refers to the extra time to process a negative. Specifically,

$$NT = \frac{\left(RT_{\text{true negatives}} + RT_{\text{false negatives}}\right) - \left(RT_{\text{true affirmatives}} + RT_{\text{false affirmatives}}\right)}{2}$$

Similarly, falsification time is the extra time required if the core propositions mismatch, namely:

$$FT = \frac{\left(RT_{\text{true negatives}} + RT_{\text{false affirmatives}}\right) - \left(RT_{\text{false negatives}} + RT_{\text{true affirmatives}}\right)}{2}$$

These concepts are discussed fully in Catlin and Jones (1976).

[3]Working independently, Singer (1977) has proposed a somewhat similar account of the picture first results for <u>below</u>, although his assumptions require the postulation of additional parameters.

Table 1

Reaction Times and Error Rates

for Sentences with Above as a Function of Order

Sentence type	Sentence	Order[a]			
		Sentence-first		Picture-first	
True affirmative	Star is above Plus	1500	(6.2)	1783	(4.7)
False affirmative	Plus is above Star	1728	(8.6)	2130	(6.8)
False negative	Star isn't above Plus	2246	(10.4)	2354	(11.2)
True negative	Plus isn't above Star	2269	(17.4)	2614	(19.5)
	Negation time =	643.5		527.5	
	Falsification time =	125.5		303.5	
	NT/FT =	5.13		1.74	

Note. Adapted from Clark and Chase (1972), Experiment 2. Reaction times are in msec.

[a]Error rates are in parentheses.

Table 2

Reaction Times and Error Rates

for Sentences with Below as a Function of Order

Sentency type	Sentence	Order[a]			
		Sentence-first		Picture-first	
True affirmative	Plus is below Star	1681	(7.8)	2139	(12.8)
False affirmative	Star is below Plus	1838	(7.0)	2077	(7.6)
False negative	Plus isn't below Star	2319	(13.3)	2678	(16.7)
True negative	Star isn't below Plus	2337	(14.3)	2499	(14.6)
	Negation time =	568.5		480.5	
	Falsification time =	87.5		-120.5	
	NT/FT =	6.50		-3.99	

Note. Adapted from Clark and Chase (1972), Experiment 2. Reaction times are in msec.

[a]Error Rates are in parentheses.

Table 3

Predictions for Sentence First Condition

	Sentence	Sentence representation	Picture	Picture representation	Comparison operations	Number of comparisons
True affirmatives	The star is above the plus	T(Star above plus)	$\left(\begin{smallmatrix}*\\+\end{smallmatrix}\right)$	(Star above plus)	$\begin{smallmatrix}+ & & +\end{smallmatrix}$	<u>k</u>
False affirmatives	The plus is above the star	T(Plus above star)	$\left(\begin{smallmatrix}*\\+\end{smallmatrix}\right)$	(Star above plus)	$\begin{smallmatrix}+ & & -\\ & & +\end{smallmatrix}$	<u>k + 1</u>
False negatives	The star isn't above the plus	F(T[Star above plus])	$\left(\begin{smallmatrix}*\\+\end{smallmatrix}\right)$	(Star above plus)	$\begin{smallmatrix}- & + & +\\ + & + & +\end{smallmatrix}$	<u>k + 4</u>
True negatives	The plus isn't above the star	F(T[Plus above star])	$\left(\begin{smallmatrix}*\\+\end{smallmatrix}\right)$	(Star above plus)	$\begin{smallmatrix} & & -\\ - & + & +\\ + & + & +\end{smallmatrix}$	<u>k + 5</u>

<u>Note</u>. Adapted from Carpenter and Just (1975).

Negation time: $\dfrac{(k + 5) + (k + 4) - [(k + 1) + (k + 0)]}{2} = 4$ Falsification time: $\dfrac{(k + 5) + (k + 1) - [(k + 4) + (k + 0)]}{2} = 1$

Table 4

Predictions for Picture First Condition

Type of problem	Picture	Picture representation	Sentence	Sentence representation	Recoding required ($\underline{r}$)[a]	Comparison operations	Number of comparisons
			Sentences with above[b]				
True affirmatives	$\left(\begin{smallmatrix}*\\+\end{smallmatrix}\right)$	(Star above plus)	The star is above the plus	T(Star above plus)	None	+ +	$\underline{k}$
False affirmatives	$\left(\begin{smallmatrix}*\\+\end{smallmatrix}\right)$	(Star above plus)	The plus is above the star	T(Plus above star)	T(Star below plus)	− + +	$\underline{k + 1 + r} = \underline{k + 2}$
False negatives	$\left(\begin{smallmatrix}*\\+\end{smallmatrix}\right)$	(Star above plus)	The star isn't above the plus	F(T[Star above plus])	None	− + + + + +	$\underline{k + 4}$
True negatives	$\left(\begin{smallmatrix}*\\+\end{smallmatrix}\right)$	(Star above plus)	The plus isn't above the star	F(T[Plus above star])	F(T[Star below plus])	− − + + + + +	$\underline{k + 5 + r} = \underline{k + 6}$
			Sentences with below[c]				
True affirmatives	$\left(\begin{smallmatrix}*\\+\end{smallmatrix}\right)$	(Star above plus)	The plus is below the star	T(Plus below star)	T(Star above plus)	+ +	$\underline{k + r} = \underline{k + 2}$
False affirmatives	$\left(\begin{smallmatrix}*\\+\end{smallmatrix}\right)$	(Star above plus)	The star is below the plus	T(Star below plus)	None	− + +	$\underline{k + 1 + r} = \underline{k + 2}$
False negatives	$\left(\begin{smallmatrix}*\\+\end{smallmatrix}\right)$	(Star above plus)	The plus isn't below the star	F(T[Plus below star])	F(T[Star above plus])	− + + + + +	$\underline{k + 4 + r} = \underline{k + 6}$
True negatives	$\left(\begin{smallmatrix}*\\+\end{smallmatrix}\right)$	(Star above plus)	The star isn't below the plus	F(T[Star below plus])	None	− − + + + + +	$\underline{k + 5}$

[a] Sentences with above ($\underline{r}$ = 1); Sentences with below ($\underline{r}$ = 2)

[b] NT/FT Ratio: Negation time ($\underline{ks}$ omitted) $\frac{(6 + 4) - (2 + 0)}{2} = 4$ Falsification time ($\underline{ks}$ omitted) $\frac{(6 + 2) - (4 + 0)}{2} = 2$

[c] NT/FT Ratio: Negation time ($\underline{ks}$ omitted) $\frac{(5 + 6) - (1 + 2)}{2} = 4$ Falsification time ($\underline{ks}$ omitted) $\frac{(5 + 1) - (6 + 2)}{2} = -1$

Table 5

Fit of the Revised Model to Picture First Data

of Clark and Chase (1972)

Including Sentences with "Above" and "Below"

Type of problem	Sentences with "above"		Sentences with "below"	
	Observed	Predicted	Observed	Predicted
True affirmative	1783	1860	2139	2121
False affirmative	2130	2121	2077	1991
False negative	2349	2381	2678	2642
True negative	2614	2642	2499	2512

Note. Intercept = 1860 msec

Slope = 130 msec

$r = .987$

RMSD = 46 msec

Table 6

Fit of the Revised Model to Picture First Data

of Clark and Chase (1972)

Separately for "Above" and "Below" Sentences

Type of problem	Sentences with "above"[a]		Sentences with "below"[b]	
	Observed	Predicted	Observed	Predicted
True affirmative	1783	1812	2139	2168
False affirmative	2130	2083	2077	2048
False negative	2349	2354	2678	2649
True negative	2614	2625	2499	2528

[a] Intercept = 1812 msec

Slope = 136 msec

r = .996

RMSD = 28 msec

[b] Intercept = 1928 msec

Slope = 120 msec

r = .993

RMSD = 29 msec

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